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Soil quality analyses under small farm holdings

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ABSTRACT

The impact of soil quality indicators under small farm holding management practices was assessed to ascertain the status of soils and their potentials for sustainable agricultural development in Kaita, Mashi and Mai-adua Local Government Areas of Northern Katsina State, Nigeria. A total of 240 soil samples were collected for physical and chemical analyses. Perception of soil quality was investigated through the administration of 600 questionnaires. The Results indicated that pH value was optimum for crop production; PBS was low, but adequate and Ec within acceptable limits across the study area. SAR, ESP and OC contents vary within the Local Governments. It was concluded that farm management practices have effects on soil quality, and ultimately, crop yield.

Introduction

The soil quality concept evolved in the 1990s in response to increased global emphasis on sustainable land use and with a holistic focus on sustainable soil management which requires more than soil erosion control. Soil quality began to be interpreted as a sensitive and dynamic way to document soil condition, response to management, or resistance to stress imposed by natural forces or human uses (Arshad and Coen, 1992; Haberern, 1992b). The sensitivity and dynamism in soil condition and its resistance to stress imposed by natural forces as ascertained by Arshad and Coen (1992) and Haberern (1992a) can be explained by the ability of plants to respond to the various changes that occur in the soil either negatively or positively. From its inception, soil quality was not limited to productivity, emphasizing instead soil management impacts on environmental quality, human and animal health, and food safety and quality (Haberern, 1992a).

Interest in the concept increased rapidly following publications on *Soil and Water Quality*: *An Agenda for Agriculture*. Several symposia and publications gave rise to several debates thereby producing definitions, identifying critical soil functions, and suggesting uses for soil quality assessments (Bezdicek, *et al*, 1996; Doran and Jones, 1996; Doran and Parkin, 1994). The concept continued to evolve with sustainable agriculture (Gomez *et. al.*, 1996) and rangeland health (NRCS, 1994) initiatives providing an increasing emphasis on sustainable land use. Soil quality assessment was envisioned as a tool to help highlight challenges associated with increasing world demand for food, animal feeds, and fiber; increasing public demand for environmental protection; and decreasing supplies of non-renewable energy and mineral resources (Pesek, 1994; Doran and Jones, 1996). Assessment tools including soil quality test kits (Liebig *et. al.*, 1996; Sarrantonio *et. al.*, 1996), farmer-based scorecards (Romig *et. al.*, 1996) and soil resource management programs (Walter *et. al.*, 1997) focus on farmer-based evaluations and education regarding various soil and crop management practices and their effects on soil resources. The accuracy, sensitivity, and usefulness of several indicators (Karlen *et. al.*, 1999; Liebig and Doran, 1999) and spatial extrapolation techniques (Smith *et. al.*, 1993) are also themes for various soil quality studies.

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Aim and Objectives

Despite the rapid development of the concept throughout the 1990s, soil quality assessment is still in its infancy. Even though extensive literature has now piled up on soil quality assessment across many areas, the geographical spread of the literature is not, because many agricultural ecosystems in dry-lands of Africa in general, and Nigeria, in particular, have not been covered. Hence this study, Soil quality analyses under small farm holdings seek to fill in such a gap and contribute to knowledge by establishing a relationship between small farm holding management practices and soil quality level in relation to crop yield.

Hypothesis:

H_1: There is no significant difference between small farm holding management practices and soil quality.

H_2: There is significant difference between small farm holding management practices and soil quality.

Materials and Methods

The Study Area:

Location and Population:

Katsina State is one of the States of the Federal Republic of Nigeria. It was created in 1987 from the former Kaduna State and is located between latitudes 11^0 08' North and 13^0 22' North and longitude 6^0 52' East and 9^0 20' East. It covers an area of approximately 23,983sq km. Katsina State is bounded to the east by Kano and Jigawa States, to the West by Zamfara State, to the South by Kaduna State and to the North by Niger Republic. The specific study area falls within the dry-land region of Katsina State, defined roughly as areas lying North of 12^0 N latitude in the state. Administratively, the following local government areas fall within the study area: Kaita, Mashi and Mai-Adua (Figure 1). The 2006 census figures put the population of the state at 5,792,578 inhabitants comprising 2,978,682 males and 2,813,896 fema

Geology and Landforms:

The northern and eastern parts of Katsina State are underlain by sedimentary rocks of cretaceous age comprising of the *Gundumi* formation. Lithologically, it consists chiefly of coarse, purple and mottled feldspatic grits. Inter-locations of bluish and purplish clays are occasionally present in the grits, while bands or horizons of quartz pebbles are common at certain levels. The sediments rest on an uneven floor of Precambrian Basement Complex rocks, although, in general, they dip at low angle to the northwest.

Fig.1: Map of Katsina State showing the study area.
Source:- NASA/NOA Spot Image 2014.

Relief, Soil and Drainage:

Katsina State is located on Nigeria's inselberg landscapes. These areas are generally undulating, characterized by numerous domed hills and occasional flat topped ridges. The region is underlain by sedimentary rocks of Cretaceous Age comprising of the '*Gundami'* formation. They are mainly made up of coarse, mottled, purple and feldspartic grits. The sediments rest on the Precambrian Basement complex. General elevation of the area is between 305 – 610 meters above sea level (Ibrahim and Maiwada, 2014). The State has two broad classes of soils. To the southern part of the State, the soils are the ferruginous type, derived from the basement complex and old sedimentary rocks. These soils are distinguished by a marked differentiation of horizons. The northern part of the State is however covered by brown and reddish brown weakly-developed soils. The sparse vegetation does not provide much litter but the plant roots that decay in the soil are responsible for much of the humus in the soil. These soils have high water and nutrient holding capacities which could make them very productive with adequate water supply. Katsina State has few perennial rivers and streams. Two major rivers in the State are Rivers *Karadua* and *Gada*. These rivers flow over the Basement Complex, thus, are characterized by rapids and falls. They flow into the *Rima* and *Sokoto* Rivers which ultimately drain into the Niger River.

Climate:

The State generally enjoys a tropical climate with distinct wet and dry seasons. The seasons are associated with the prevalence of southwest monsoon which is moisture laden from the Atlantic Ocean and the dry continental northeast trades from the Sahara Desert. The boundary between the air masses known as the Inter-Tropical Convergence Zone separates the distinct patterns of weather on either side. This convergence zone has seasonal fluctuations which in effect also determine moisture distribution. Generally rainfall decreases from the coast inwards, both in amount and duration. Katsina, being in the interior, witnesses rainfall for a shorter period than the regions along the coast. When the inter-tropical convergence zone moves northwards around late May, the rainy season sets in. During this time, the south west moisture laden monsoon winds are dominant. The rainy season continues up to late September when it begins to disappear. There is a single peak in the month of August. Average rainfall range between 400 – 1000mm per annum. From October to early May, is a long dry season with little or no rain.

Temperatures in the area vary with the seasons. There is a warm wet season between the months of June and September. Temperatures are as high as between 30^0C and 37^0C. These high temperatures are moderated by the effect of the rain. The period after the rains is marked by a drop in relative temperature with temperature falling as low as 22^0C. During the months of December to February, temperature is low due to the effect of the cool, dusty harmattan winds blowing from the north. Night time temperatures at times fall to as low as 18^0C. The months following these are however hot months especially the months of March to May when the sun is directly overhead. Temperatures during these times exceed 37^0C.

Just like the rains, humidity is highest along the coast and decrease towards the hinterland. In the study area, the highest values are between 76-87% and occur in the month of August when the rains are at maximum, while the lowest values of 10 – 25% are obtained between the months of November to March, when there is hardly any moisture in the atmosphere.

Vegetation:

Vegetation cover in Katsina state is a mixture of Sudan and Sahel Savannah. Total vegetation cover is small with widely dispersed trees. The landscape is generally characterized by short shrubs that form bushes, widely scattered and drought resistant trees with extensive grasslands. This occurs mostly in the northern axis. The reforestation scheme in the State has succeeded in getting lots of trees and woodlands planted and nurtured. The southern part of the State is however covered by the Sudan Savannah type of vegetation. This is marked by continuous grass cover interspersed by short Savannah trees such as the *acacia*. Intense cultivation, bush burning and overgrazing have depleted the grass cover over large tracts.

The State lies within the Sudan Savannah zone but its vegetation has, to a large extent, been modified as a result of several centuries of bush clearing for construction activities, bush burning, cultivation, animal grazing as well as fuel wood exploitation. In the closely settled area especially around Katsina town, natural vegetation is almost absent but several trees have been planted including *Azadiracta indica* and *Acacia albida*. A considerable growth of natural vegetation occurs in areas that are marginal and not cultivated. The vegetation is generally characterized by sparse trees, grasses and shrubs. The trees are normally short ranging between 3 to 8 meters. Most trees in this area are drought resistant such as *Adansonia digitata*. Most of the shrubs dominating the area are short while some are thorny. The rooting depth of both trees and shrubs is very deep so that they can access moisture from underground. Grasses in the area are also resistant to moisture scarcity and have the ability to re-grow after dormancy as a result of lack of moisture. Most of the vegetation is dispersed, while others are concentrated in particular land use types. However, some of the plants occur in a large number while the number of some has been limited mostly through bush clearing and the land being utilized for different purposes.

Types and Sources of Data:

The data used in this work were obtained from two major sources, primary and secondary. The primary source was in three stages; pre-field, field and post field stages. The pre-field stage consists of the preparation of questionnaire and the study of the site to determine how the samples would be collected. Field stage involves the collection of soil samples and the administration of structured questionnaire to obtain information on the various forms and activities of small farm holding practices in the study area. While the post field stage consists of laboratory analysis of soil samples collected and the analysis of questionnaire administered. The secondary source of information is made up of literature review.

Sampling Techniques and Sample Size:

The study area is made up of three Local Government Areas comprising of Mashi, Mai-adua and Kaita. The sample size for the purpose of the administration of the questionnaire is 600, with 200 copies of questionnaires administered in each of the Local Government Areas. A total of 442 copies of the administered questionnaires were retrieved with 146 retrieved from Mashi, 147 from Mai-adua and 149 from Kaita Local Government Areas respectively. Composite random sampling technique was used to collect data and before the administration of the questionnaires, there was a selection of the farms to be used for soil sample collection, which included farms that are not less than 1 hectare and not more than 2 hectares. Based on the above criteria from each of the three Local Government Areas, four farm sites were selected which were coded sites A, B, C and D for the purposes of analysis. The settlements close to the selected farm sites where most of the farmers live served as base for the administration of the questionnaire.

Data Collection:

From each of the selected farmlands comprising 12 plots, 20 soil samples were collected at a distance of 30 meters apart to ensure that the points were not too far from each other and in order to determine the rates of changes occurring in the nutrient levels and other characteristics of the soils. Soils were collected at a depth of 30cm with the aid of a soil auger as adopted by Essiet (1990).

Data Analysis:

Laboratory Analysis:

Soil samples were air dried and sieved through 2mm mesh before analysis for their physical and chemical properties in the Laboratory.

Particle Size Analysis:

Particle size analysis was carried out using Bouyoucos hydrometer method as described by Black (1975). The textural classes of the soils were determined using Marshall's textural triangle.

Soil pH:

pH was measured in soil water suspension which was determined using glass electrode digital pH meter as described by Black (1975).

Total Nitrogen (N):

The regular macro-Kjedahl method was used to determine Nitrogen (N) in each of the soil samples as described by Black (1975). The percentage N in the soils was calculated using the following formula:-

$$N = \frac{a \times n \times 0.014}{w} \times 100 \text{ -------------------------- } (1)$$

Where: a =amount of hydrochloric acid (HCl) used for titration (M/S)

n =normality of HCl

w=mass of sampled soil (g)

0.014=constant

Available Phosphorus (P):

Available phosphorus was determined using the bicarbonate method as described by Olsen, *et. al.* (1964).

Exchangeable Cations:

Exchangeable cations were extracted with IN ammonium acetate solution each. The concentrations of Na^+ and K^+ were determined using flame photometer, while Ca^{++} and Mg^{++} were determined by titration with 0.02N EDTA solution as described by Page, *et. al.* (1982).

Organic Carbon:

Organic carbon content was determined using the dichromate wet oxidation method as described by Walkley and Black, (1968).

Statistical Analysis:

The questionnaires were analyzed by encoding responses to the questions on a spread sheet in Excel which were exported to Statistical Package for Social Scientist (SPSS) environment for hypothesis testing. The data were organized in the spread sheet such that each question in the survey was represented by a column and each observation was represented by a row. The coding pattern used in this study is as shown in Table 1. Descriptive statistics of mean, variance and standard deviation were used to summarize the soil data for the selected locations. ANOVA statistical analysis was used to test the hypothesis.

Table 1: Coding used in the Study

Question type	Codes
Dichotomous	1 for male 2 for female
Frequency/agreement	1 for never 2 for rarely 3 for sometimes 4 for usually 5 for always
Categorical	1 for individual 2 for single parent 3 for nuclear 4 for extended
Scale	As given, e.g. age 34

Source: Field Survey

Results & Discussion:

The status of soil in Mashi Local Government Area with pH values of 6.5 for site A is within the permissible range, while those of sites B, C and D are slightly below the permissible range of between 6.5 and 8.4. The Electrical Conductivity (EC) of site A is 0.4mmhOS/cm, B is 0.5mmhOS/cm, C is 0.3mmhOS/cm and D is 0.41mmhOS/cm. The Percentage Base Saturation (PBS) for sites A, B, C and D are 40.9%, 36.6%, 46.8% and 53.1% respectively. Total Nitrogen is almost negligible across the study area in Mashi with site D having the least value of 0.08%. The Organic Carbon (OC) of soil samples across this study area are generally very low with location A having the lowest value of 1.7%, followed by the site D (1.99%), and 2.3% and 2.4% for sites C and B respectively.

The status of soil in Mai-adua Local Government Area with pH values of 6.0 for site A also fell below the permissible range of 6.5 to 8.4, while those of sites B, C and D are within the permissible range, with locations B and D having pH values of 6.9 each and site C has a pH of 6.7. The Electrical Conductivity (EC) of sites A, C and D are 0.5mmhOS/cm each, while that of site B is 1.9mmhOS/cm. The Percentage Base Saturation (PBS) for sites A, B, C and D are 39.7%, 44.2%, 36.6% and 39.4% respectively. Total Nitrogen is almost negligible across Mai-adua with sites A and C having the least values of 0.1% each. The values of Ca, are 2.3, 2.8, 3.2 and 5.5 respectively for sites

A, B, C, and D, those for Mg are 1.9, 2.5, 3.6 and 4.5, values of K are 6.5, 3.6, 4.1 and 5.1 and Na has values of 1.3, 1.3, 2.7 and 1.6 for sites A, B, C and D respectively. The percentage values of OM are 2.5, 4.2, 4.1 and 2.2 for sites A, B, C, and D respectively. While the percentage values for Organic Carbon (OC) are 1, 4.6, 3.5 and 2.5.

The status of soils in Kaita Local Government Area is that it has pH values below the permissible range of 6.5 to 8.4, with values of 6.2, 5.9, 5.8 and 5.5 respectively for sites A, B, C and D. The Electrical Conductivity (EC) of sites A, B, C and D are 0.6mmhOS/cm, 6.4mmhOS/cm, 2.6mmhOS/cm and 1.1mmhOS/cm respectively. The Percentage Base Saturation (PBS) for sites A, B, C and D are 36.6%, 30.7%, 40.6% and 54.8% respectively. Total Nitrogen is almost negligible across the study area in Kaita Local Government Area with site D having the least value of 0.1%, locations B and C each has 0.2% while site A is 0.3%. The values of Ca, are 4.1, 6.1, 3.6 and 2.4 respectively for sites A, B, C, and D, Mg has values of 4.0, 5.6, 3.6 and 6.3, values of K are 3.8, 6.9, 4.5 and 3 and Na has values of 7, 7.7, 5.3 and 0.7 for sites A, B, C and D respectively. While the percentage values for Organic Carbon (OC) are 0.7, 0.7, 1.4 and 4.4 respectively for sites A, B, C and D.

The elements considered as affecting soil quality with regard to nutrient availability across the three local government areas that make up the study area are phosphorus, potassium, organic content and Nitrogen. pH is excluded as it can sustain optimum integrated plant production and environmental quality. In Mashi local government area, the values of phosphorus is 5.17, potassium is 1.24, organic content is 2.06 and Nitrogen is 0.15, all of which fell below the range of indicators as compared with the standard range of soil quality indicators based on Harris, *et. al.* (1996).

The values of the elements affecting soil quality in Mai-adua Local Government Area are phosphorus (3.1), potassium (4.83), organic content (2.9) and Nitrogen (0.18). All of these fell below the range of soil indicators of Harris *et. al.* (1996).

The values of the elements affecting soil quality in Kaita Local government Area are phosphorus (4.33), potassium (4.55), organic content (1.8) and Nitrogen (0.2) which fell below the range of soil quality indicators of Harris *et. al.* (1996).

The impact of soil properties on small farm holdings in the study area can be seen in the osmotic effect which is as a result of the saline soils that gave rise to problems of late maturity, decreased crop yields and plant diseases as observed in the area.

The identified small farm holding management practices include contour, strip cropping, vegetation crop cover, grassed water ways, tree planting, mulching, use of fertilizers, composting and manuring, intercropping, mixed farming and agro-forestry.

Farming practices on which the identified small farm holding management practices are carried out includes mono-cropping, mixed cropping and mixed farming. The tillage practices in the area range from hand labor through drought power to the use of tractors. Associated farming problems in the area are drought, stunted growth, and late maturity as well as various plant diseases and soil erosion which are the most prevailing problems across the area.

The major crops grown in the identified small farm holding management practices are millet, guinea-corn, cowpea, sesame, bambara-nuts, sweet-potatoes, maize and groundnut. The average number of plants per stand for the various crops is as follows: millet between 4 and 5, guinea corn 3 to 4, maize 3 and groundnut 3 to 4 per stand with a spacing of between row and within row of 60 X 90, 60 X 60, 25 X 75 and 45 X 75 for millet, guinea corn, maize and groundnut respectively. The estimated crop yields/kg/ha is 66,313; 55,271; 43,960 and 62,420 for millet, guinea-corn, maize and groundnut respectively.

The consequences of agricultural practices on the environment include deforestation, soil degradation and erosion as well as biodiversity loss. The combine effects of each of these on the environment include increased temperatures, high rates of evaporation, surface and underground water shortages, reduced yields, livestock mortality and destructions by winds. The resultant effects of biodiversity loss on the environment include extinction of plants and animal species, and disappearance of medicinal herbs, while consequences of soil degradation and erosion on the environment are the evolution of Bad-lands, hard-pan and poor soils. The resultant effects of desertification on the environment are similar to those produced by deforestation and soil degradation and erosion.

Conclusion and Recommendations

Conclusion:

Considering the ESP values of 12.18, the soils in Mashi Local Government Area can be concluded to be sensitive to plant growth. The same for Mai-adua Local Government Area which had ESP values of 12.2, while those of Kaita (ESP values 7.49) are concluded to be extremely sensitive to plant growth. The SAR in Mashi Local Government Area is 2.52, thus, the soils are concluded to have negligible amount of salt accumulation. While in Mashi Local Government Area, (SAR values of 3.34) the soils have increasing amount of salt accumulation, just like those of Kaita, (SAR values of 4.46). Despite the nutrient deficiency in phosphorus, potassium, organic content and nitrogen in the soils of the study area and with the low ESP values of 12.18, 12.2 and 7.49 for Mashi, Mai-adua and Kaita Local Government Areas respectively, the physical properties of the soil are still considered to be in good condition. Based on these findings, it is therefore concluded that there is significant relationship between soil properties and crop yield across the study area. However, no significant difference between small farm holding management practices and soil quality under cultivated farm plots was established. This clearly shows that the soil quality is closely related to the various farm management practices carried out by farmers across the study area, implying that crop yield is a function of soil fertility in the area.

Recommendations:

Since soil quality is significantly related to the various farm management practices as revealed in the study, farm management practices such as mixed farming to make use of animal dung as manure, intercropping, mulching to retain soil moisture and check excessive evaporation of soil water, tree planting and the use of check dams to check wind and water erosion respectively where prevalent, vegetation crop cover to provide manure in form of green manure and the use of compost manure to improve the level of soil nutrient should be encouraged in the management of small farm holdings. Similarly, due to the deficiency in phosphorus, potassium, organic content and nitrogen in the soils of the study area, application of fertilizers to boost these elements should be encouraged. Furthermore, constant use of irrigation water should be encouraged among farmers to reduce the effect of salt accumulation in the soils. This is taking into cognizance of several earth dams lying idle across the State. Annual soil testing is recommended to assess possible sodium problems in the study area. Government should also evolve a policy that will increase the sizes of small farm holdings in the area and encourage the formation of cooperatives with a view to improving farmers' capacities and capabilities in food production, economic activities and general well-being. Research findings and new innovations on farming and environmental protection should be made in local languages and accessible to farmers for ease of adaption. Any technology adopted should also be tested locally before adaption. Community Shelter Belts and production of briquettes using saw dust waste and coal should be encouraged to reduce the persistent felling of trees in search for fuel woods. This will reduce the effects desertification, global warming and unclean environment, while the establishment of Soil Management Commission in the state will help regulate land use in the area.

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